



**EPRI**

ELECTRIC POWER  
RESEARCH INSTITUTE

## System Compatibility

## LED Street Lights

**Tom Geist**

Senior Project Manager

**Municipal Consortium Southwest  
Region Workshop**

September 30, 2010, Los Angeles,  
California

# Birds are Compatible...(Mostly)



# Cars are Not!



# What About LED Street Lights?







# Agenda

- The importance of LED street lights  
*and system compatibility*
- Information on EPRI
- Three criteria for system compatibility
  - Function, survive, no side effects
- Answers to some basic questions
- Where do we go from here...

## Point #1 ... It Matters!



*Our future depends on it.*

Potential savings of  
4,500 MWh  
per year.\*

Equivalent to seven  
1,000 MW power plants

Equivalent to  
3.7 million households

\*Assumes 100% installed base. Source: Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications, U.S. Department of Energy, September 2008.

# Its Your Money...

- Mayor cuts pay of Albuquerque cops...
- Philadelphia mayor cuts 2010 budget, city jobs...
- Kansas City Braces for School Closings, Budget Cuts...



- ... Mayor Nutter Signs Legislation, Announces Measures to **Increase Energy Efficiency** and **Save Money**



## It's Your Industry...



*In 1938 the first mercury vapor streetlights were installed...*

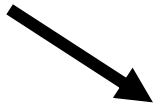
Light Source	Percentage	Number of Street and Area Lights
Incandescent	2	3,159,000
Halogen Quartz	8	9,917,000
Fluorescent	6	7530,000
Mercury Vapor	13	17,675,000
Metal Halide	27	38,330,000
High Pressure Sodium	39	54,754,000
Total	100	131,356,000

*... and many are still there.*

Source: Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications. U.S. Department of Energy, September 2008.

# Its Your Career...

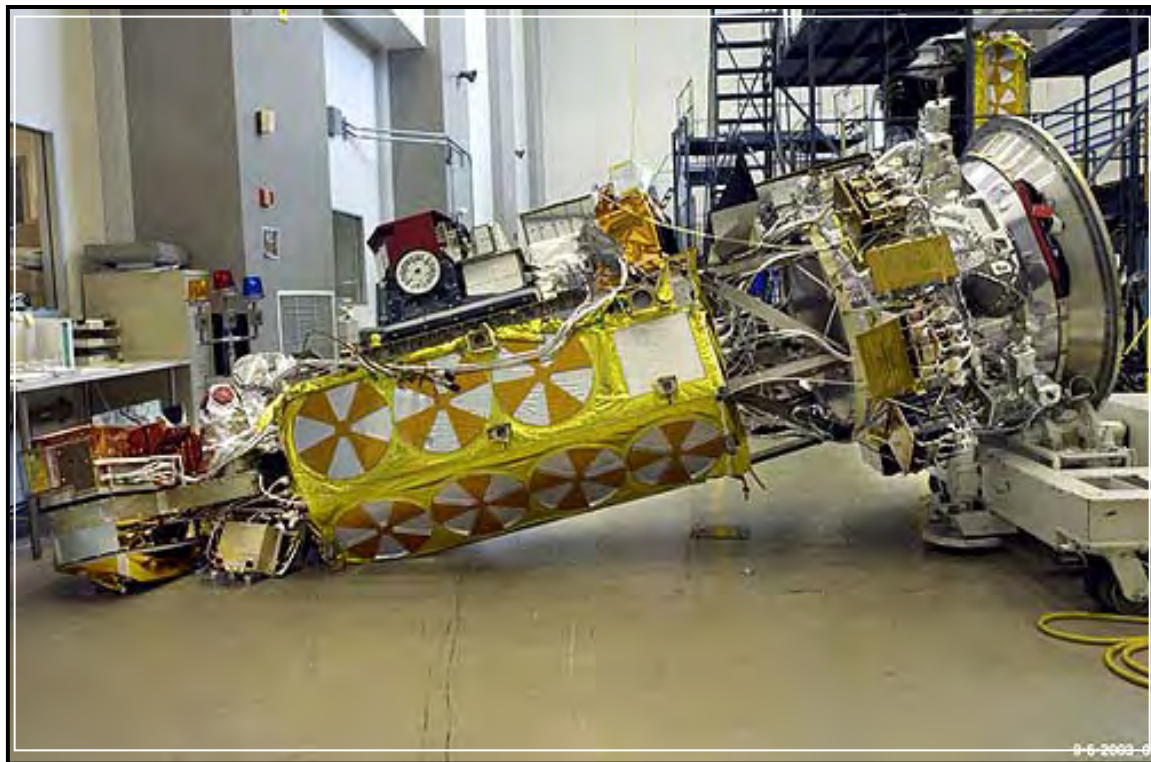
## LED Fixture remorse



*...don't let this  
happen to you.*

# Failure Leads To...

- Lost jobs
- Lost revenue
- Lost opportunity for energy savings.



# Our History...

- Founded by and for the electricity industry in 1973
- Independent, nonprofit center for public interest energy and environmental research
- **Collaborative** resource for the electricity sector
- Major offices in Palo Alto, CA; Charlotte, NC; Knoxville, TN
  - Laboratories in Knoxville, Charlotte and Lenox, MA

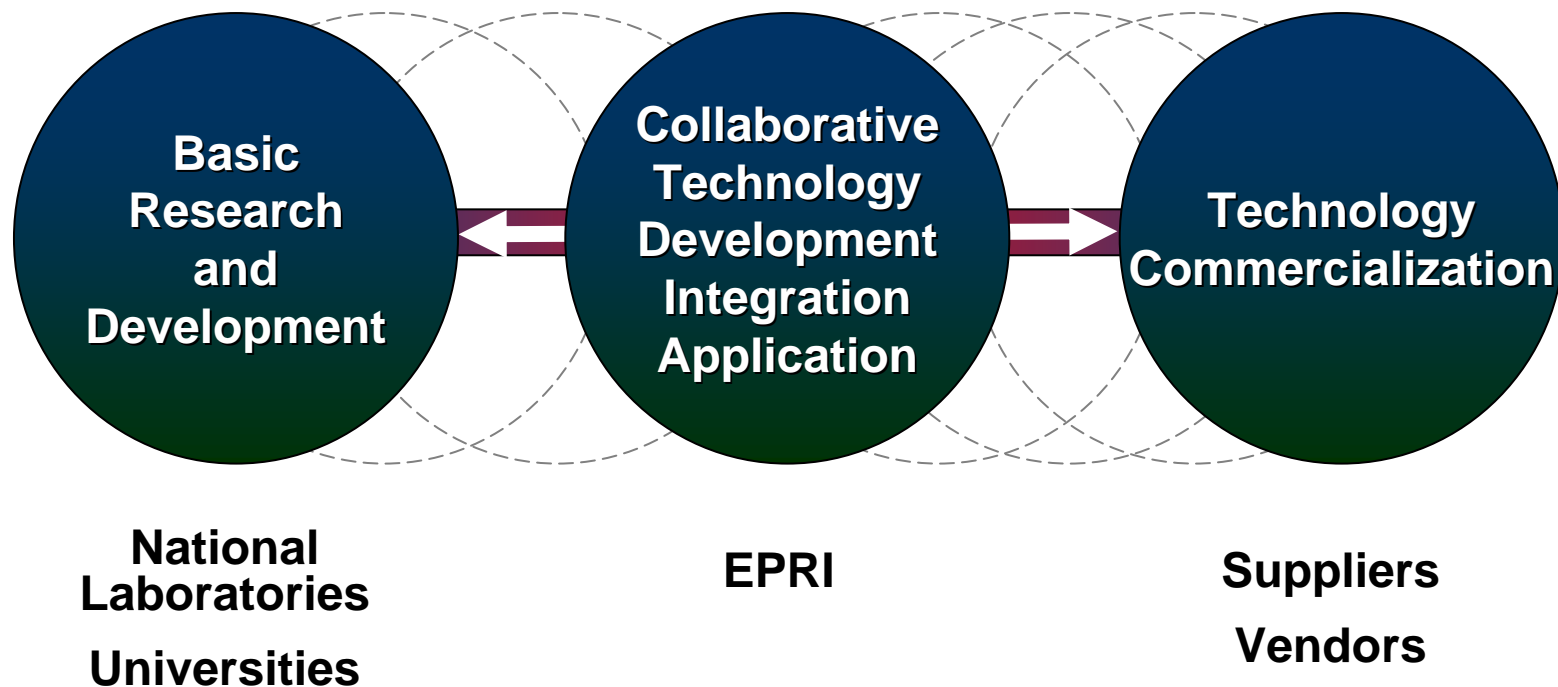


**Chauncey Starr**  
EPRI Founder



## Our Role...

*Help Move Technologies to the Commercialization Stage...*



***Technology Accelerator!***



# How Did We Obtain Our Expertise?

- Began Building Knowledge Base in mid-1990s
- We've Performed System Compatibility Walkthroughs and Audits Worldwide
- Performed Hundreds of On-Site Tests of Machines and Process Equipment in many industries.
- Years of collaboration with Utilities, industry and equipment providers
- Active in development of System Compatibility and Power Quality Standards



*PLCs*

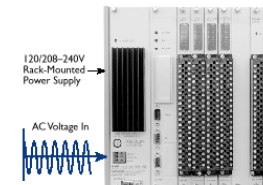
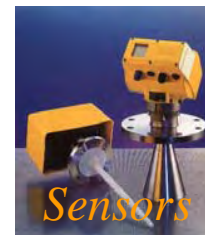


Figure 1. A rack-mounted PLC power supply that requires AC voltage (120/208-240 volts)



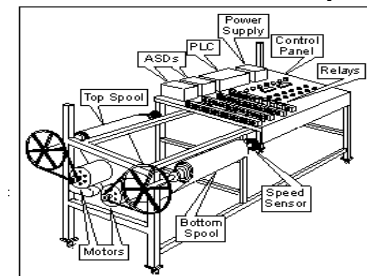
*Power Supplies*



*Sensors*

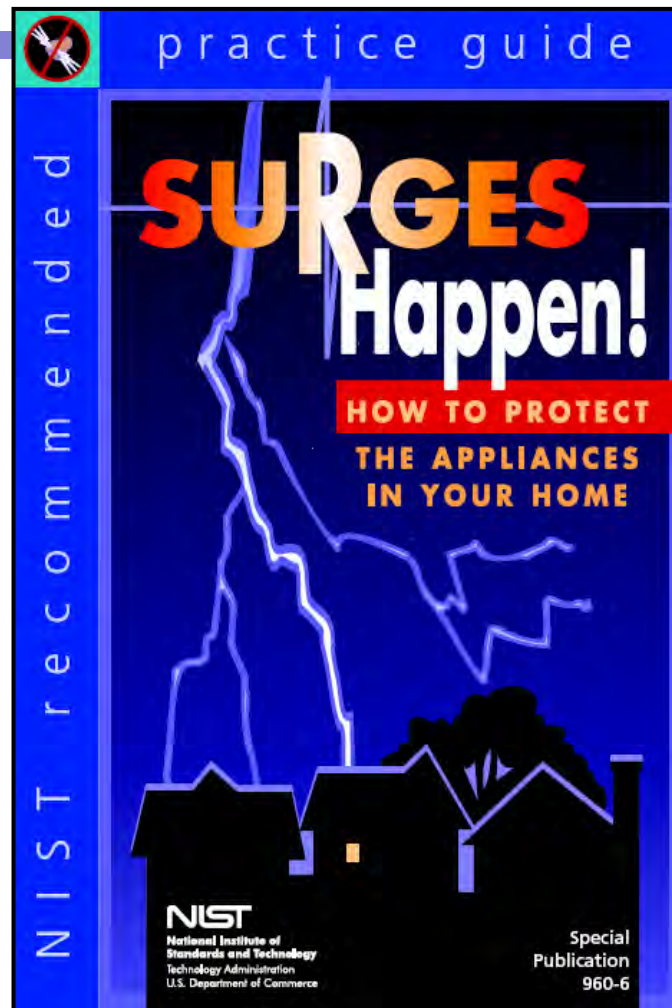


*Process Mockups*



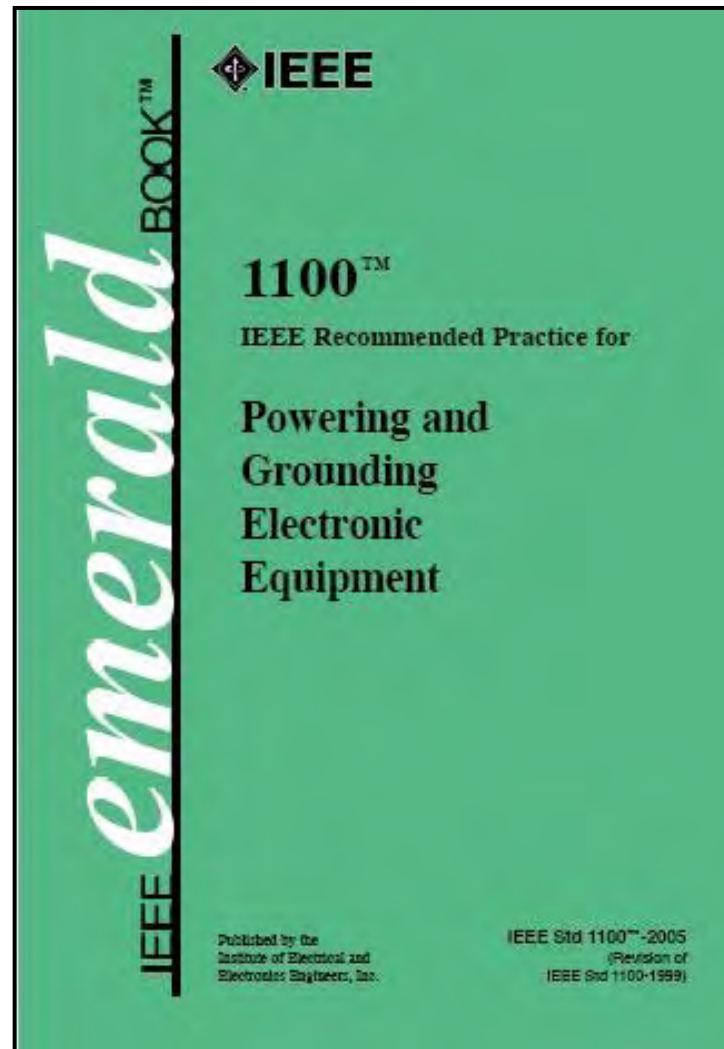
*Relays, Contactors,  
Motor Starters*

## Get the Book



Free download: [http://www.pueblo.gsa.gov/cic\\_text/housing/surge/surge.pdf](http://www.pueblo.gsa.gov/cic_text/housing/surge/surge.pdf)

# Get the Green Book



Chapter 3.

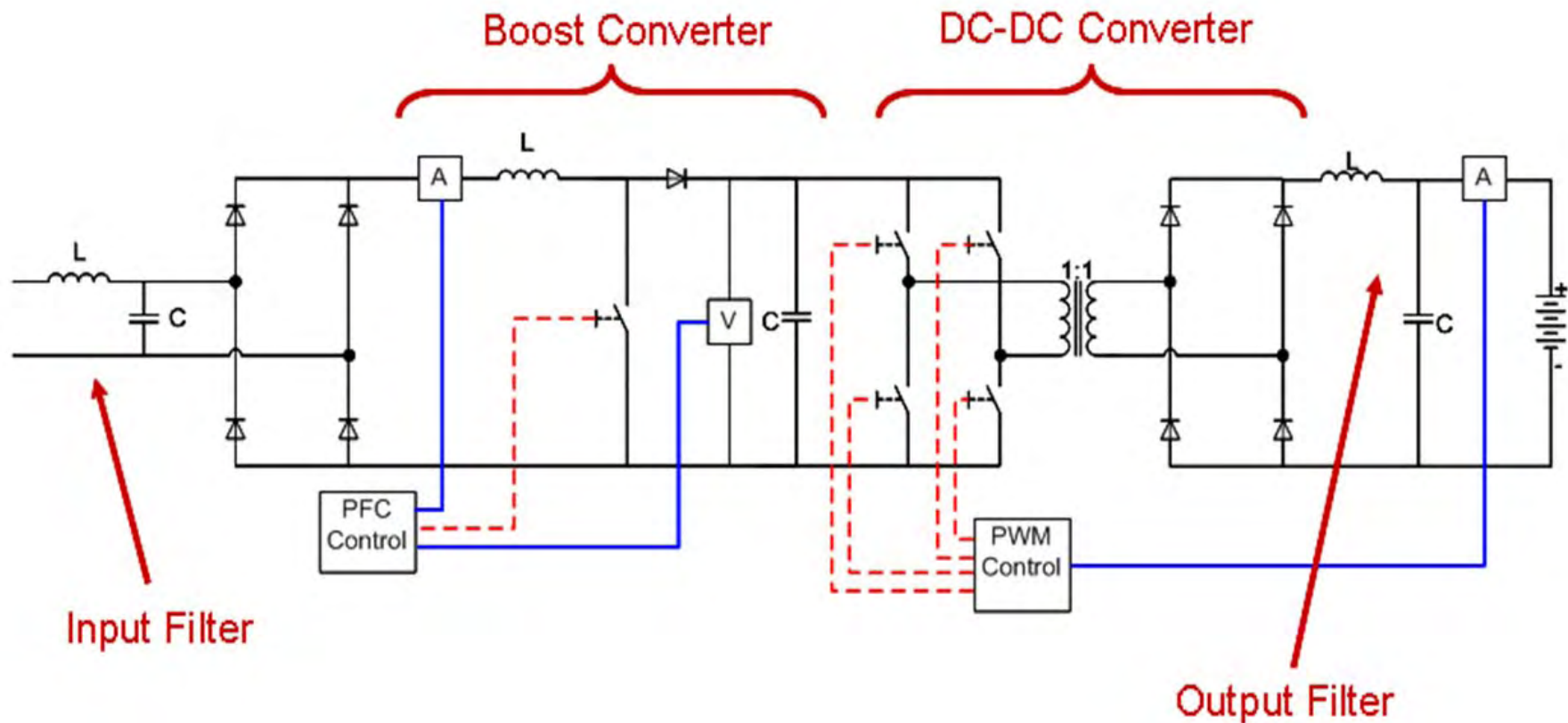
# Three Criteria for System Compatibility

Equipment Must:

- **Function** as intended
- **Survive** the electrical environment
- **No side effects** to equipment or environment

# Generic Schematic

- Function as intended
- Survive the electrical environment
- No side effects to equipment or environment



PFC = power factor correction

PWM = pulse width modulation



# Driver Performance



**Function** as intended

**Survive** the electrical environment

**No side effects** to equipment or environment

- In addition to lighting performance, what about driver performance?
  - Reliability
  - Output regulation
  - Output ripple (either current or voltage)
  - Transient operation (on/off)
  - Steady-state overvoltage and undervoltage
  - Efficiency
  - Temperature

*“The driver consists of power electronics used to shape utility supplied voltage and current into a form compatible with LEDs.”*

# The Fixture Goes Where?

Function as intended

→ Survive the electrical environment

No side effects to equipment or environment

## *Direct Lightning Strike*

- 13.2 kV Primary Distribution Line
- Resulted in fault and conductor burn down
- Sustained interruption of several hours

Photograph courtesy of Niagara Mohawk



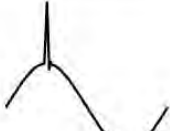



# Survive

Function as intended



Survive the electrical environment

No side effects to equipment or environment

Electrical Disturbance	Cause of Disturbance
 <p>Impulsive</p> <p>Transients (Surges)</p>  <p>Oscillatory</p>	<ul style="list-style-type: none"> <li>• motors in air conditioners, HVAC equipment, elevators, water coolers, fans</li> <li>• lightning</li> <li>• photocopiers and laser printers</li> <li>• static discharge</li> <li>• routine utility activity</li> <li>• electronic air ionizers</li> <li>• kitchen appliances</li> </ul>
 <p>Noise</p>	<ul style="list-style-type: none"> <li>• HVAC equipment</li> <li>• kitchen appliances</li> <li>• light dimmers</li> <li>• electronic lighting</li> <li>• electronic air ionizers</li> <li>• radios, telephones</li> <li>• Overhead Lines</li> <li>• Building Transformers</li> <li>• vacuum cleaners</li> </ul>
 <p>Harmonic Distortion</p>	<ul style="list-style-type: none"> <li>• computers</li> <li>• televisions, video cassette recorders</li> <li>• electronic lighting</li> </ul>

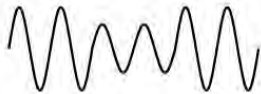
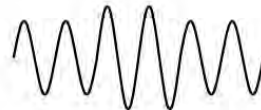
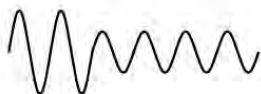
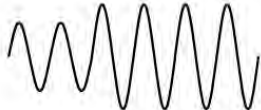
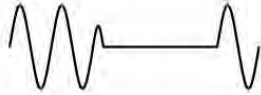
# Survive

Function as intended



Survive the electrical environment

No side effects to equipment or environment

Electrical Disturbance	Cause of Disturbance
 Sag	<ul style="list-style-type: none"> <li>• motors in air conditioners, HVAC equipment, elevators, water coolers, fans</li> <li>• photocopiers and laser printers</li> <li>• routine utility activities</li> </ul>
 Swell	<ul style="list-style-type: none"> <li>• motors in air conditioners, HVAC equipment, elevators, water coolers, fans</li> <li>• photocopiers and laser printers</li> </ul>
 Undervoltage	<ul style="list-style-type: none"> <li>• improper wiring and grounding</li> <li>• improper voltage tap adjustment</li> <li>• defective building transformer</li> </ul>
 Overvoltage	<ul style="list-style-type: none"> <li>• improper wiring and grounding</li> <li>• improper voltage tap adjustment</li> <li>• defective building transformer</li> <li>• crossed power lines</li> </ul>
 Interruption	<ul style="list-style-type: none"> <li>• lightning</li> <li>• tripped circuit breaker, blown fuse</li> <li>• downed power lines</li> </ul>

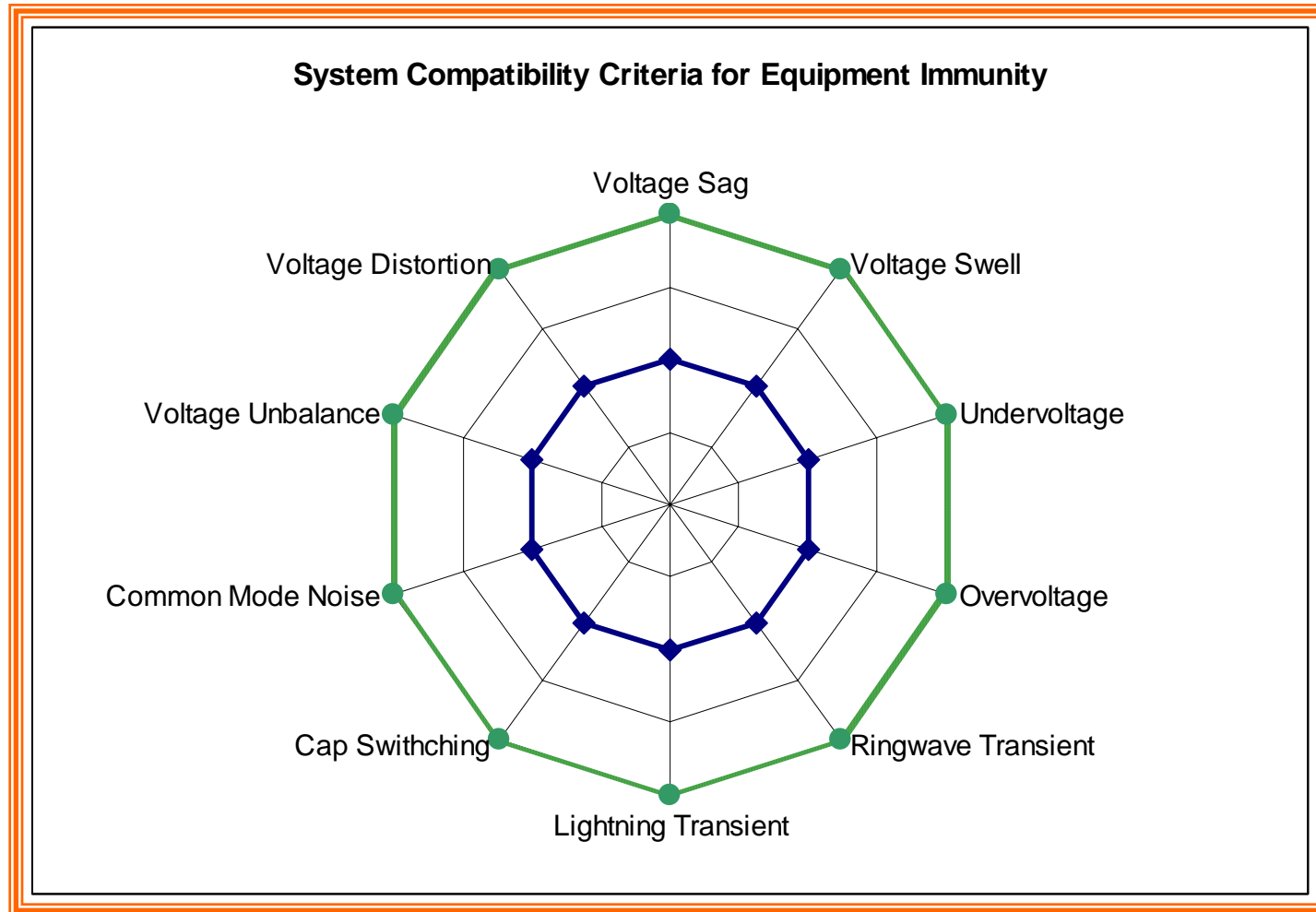
# Survive

Function as intended



Survive the electrical environment

No side effects to equipment or environment





# Survive

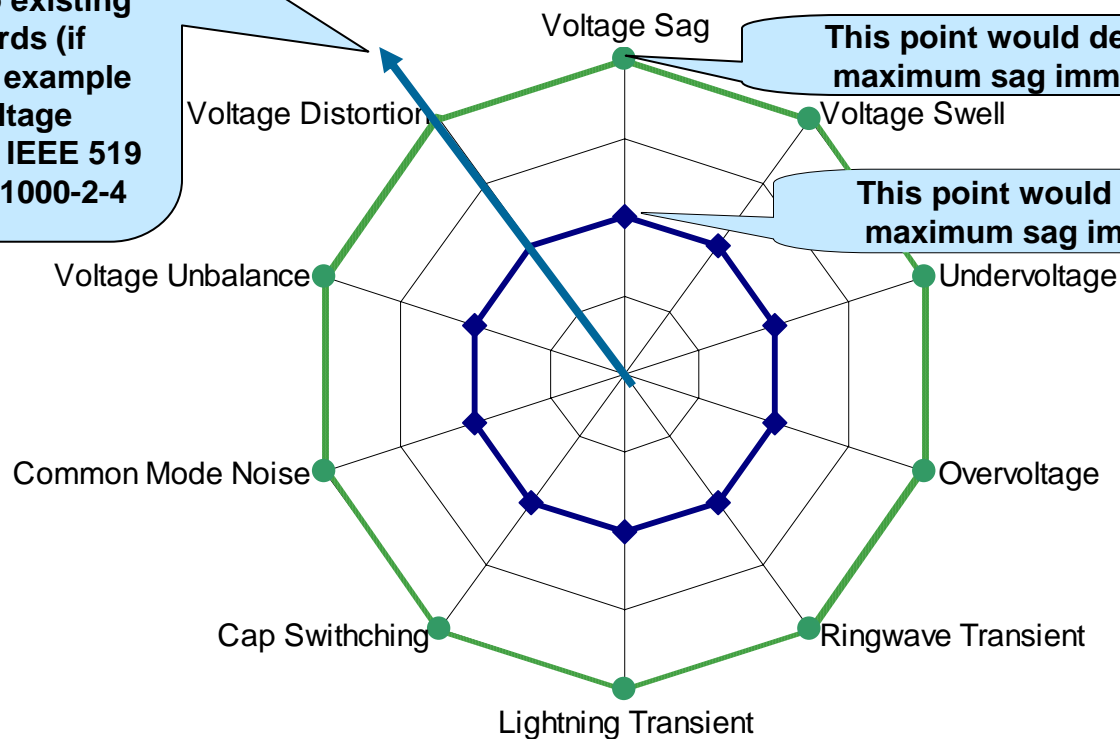
Function as intended

→ Survive the electrical environment

No side effects to equipment or environment

Each parameter and the min/max values are tied to existing standards (if available) example for voltage distortion: IEEE 519 and IEC 61000-2-4

## System Compatibility Criteria for Equipment Immunity



This point would define the maximum sag immunity spec

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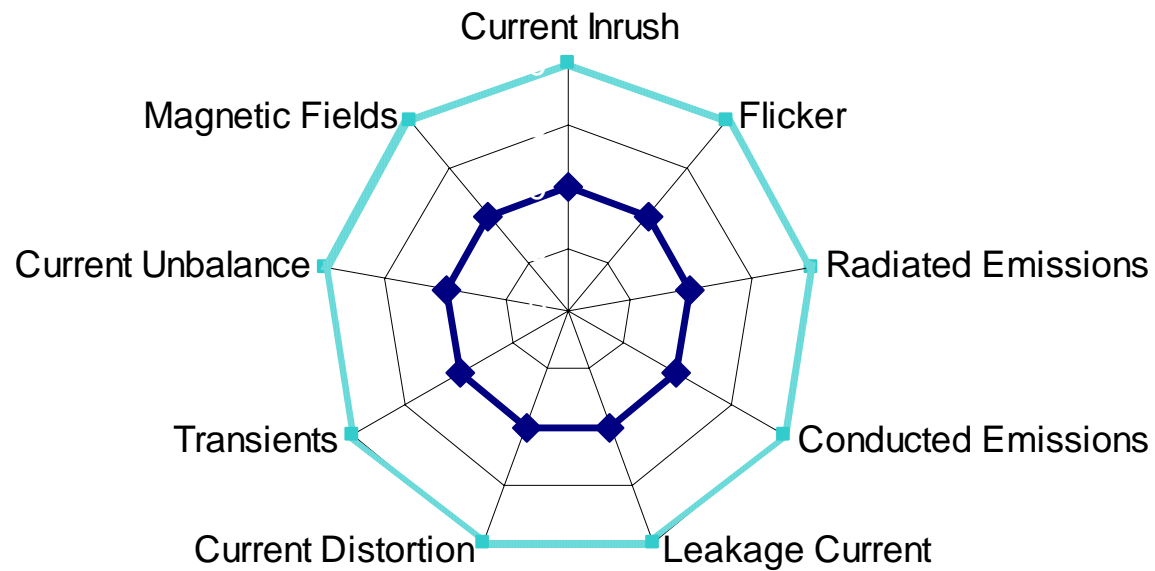
# No Side Effects

Function as intended

Survive the electrical environment

→ No side effects to equipment or environment

## System Compatibility Criteria for Equipment Emissions



→ **Survive** the electrical environment

→ **No side effects** to equipment or environment



# Frequencies of Interest...

Function as intended

Survive the electrical environment

→ No side effects to equipment or environment

## Small Signal

Source	Frequency (MHz)	Output Power (W)	Estimated Field Strength (V/m) <sup>†</sup>
Paging Transmitters	49	250	110*
Walkie-Talkies	27, 49, 145, 450	5	15*
State Police Radio	39	100	40
Biomedical Telemetry	174–216	0.8 $\mu$ W	0.006*
	460–470	0.002	0.3*
	512–566	0.1 $\mu$ W	0.002*
Mobile Radios	440–470	25	35*
Police/Ambulance	400–900	10–100	22–70*
Wireless LANs	912	0.1	2.2
Personal Digital Assistants	896–940	4	14
Radio Modems	896–901	10	22
Cellular Telephones	800–900	0.6–3	5.4–12
Personal Com. Service	1850–1950	0.2	3

<sup>†</sup>Measured at one meter.

\*Distance is within the “near field,” which includes an electric field and magnetic field.

Source: Association for the Advancement of Medical Instrumentation, *Guidance on Electromagnetic Compatibility of Medical Devices for Clinical/Biomedical*, Technical Information Report AAMI TIR No. 18—1997.

# Frequencies of Interest...

Function as intended

Survive the electrical environment

→ No side effects to equipment or environment

## Large Signal

Source	Frequency (MHz)	Maximum Licensed Radiated Power (W)	Estimated Field Strength (V/m) <sup>†</sup>
Amateur Radio	1.8 MHz–300 GHz	1,500	0.1*
AM Radio Broadcast	0.535–1.705	50,000	0.7*
FM Radio Broadcast	88–108	100,000	0.9
TV Channels 2–6	2, 3, 4: 54–72	100,000	0.9
	5 and 6: 76–88		
TV Channels 7–13	174–216	316,000	1.7
TV Channels 14–69	470–806	5,000,000	6.7

<sup>†</sup>Measured at one kilometer.

\*Field strength may be greater if directional antennas are used.

Source: Association for the Advancement of Medical Instrumentation, *Guidance on Electromagnetic Compatibility of Medical Devices for Clinical/Biomedical*, Technical Information Report AAMI TIR No. 18—1997.

# A Quick Story...

Function as intended

Survive the electrical environment



No side effects to equipment or environment



*“We need to remember the lessons learned from our experience with compact fluorescents.”*



# Case Study - Emissions

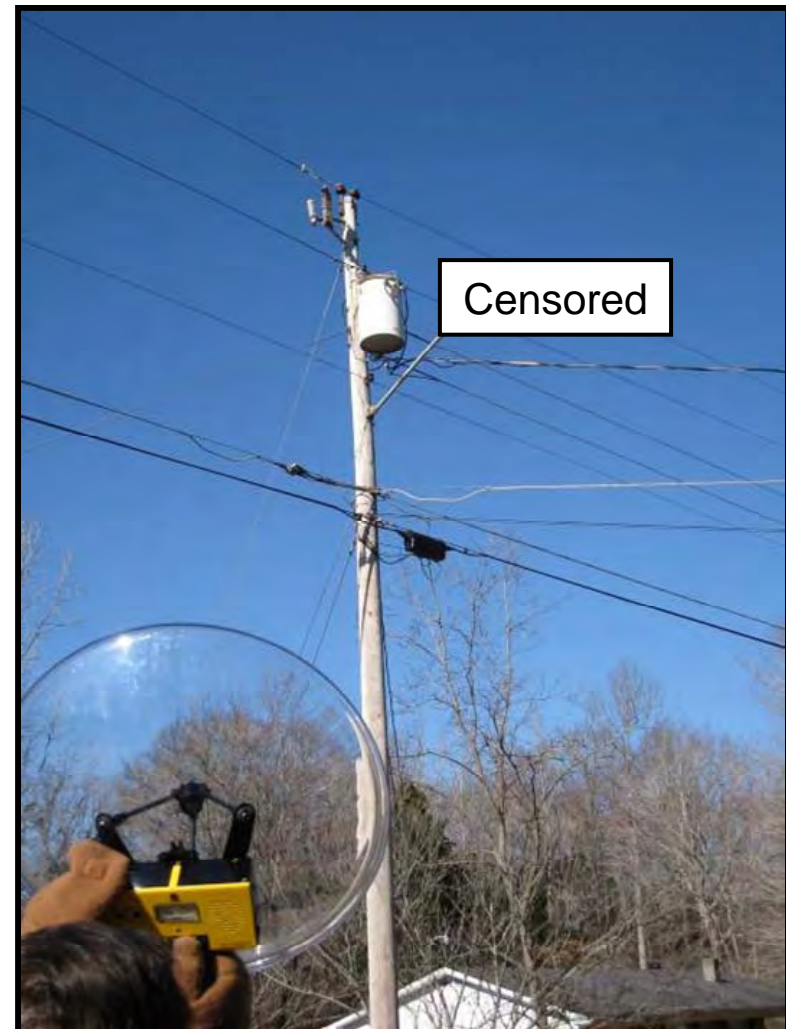
Function as intended

Survive the electrical environment

→ No side effects to equipment or environment

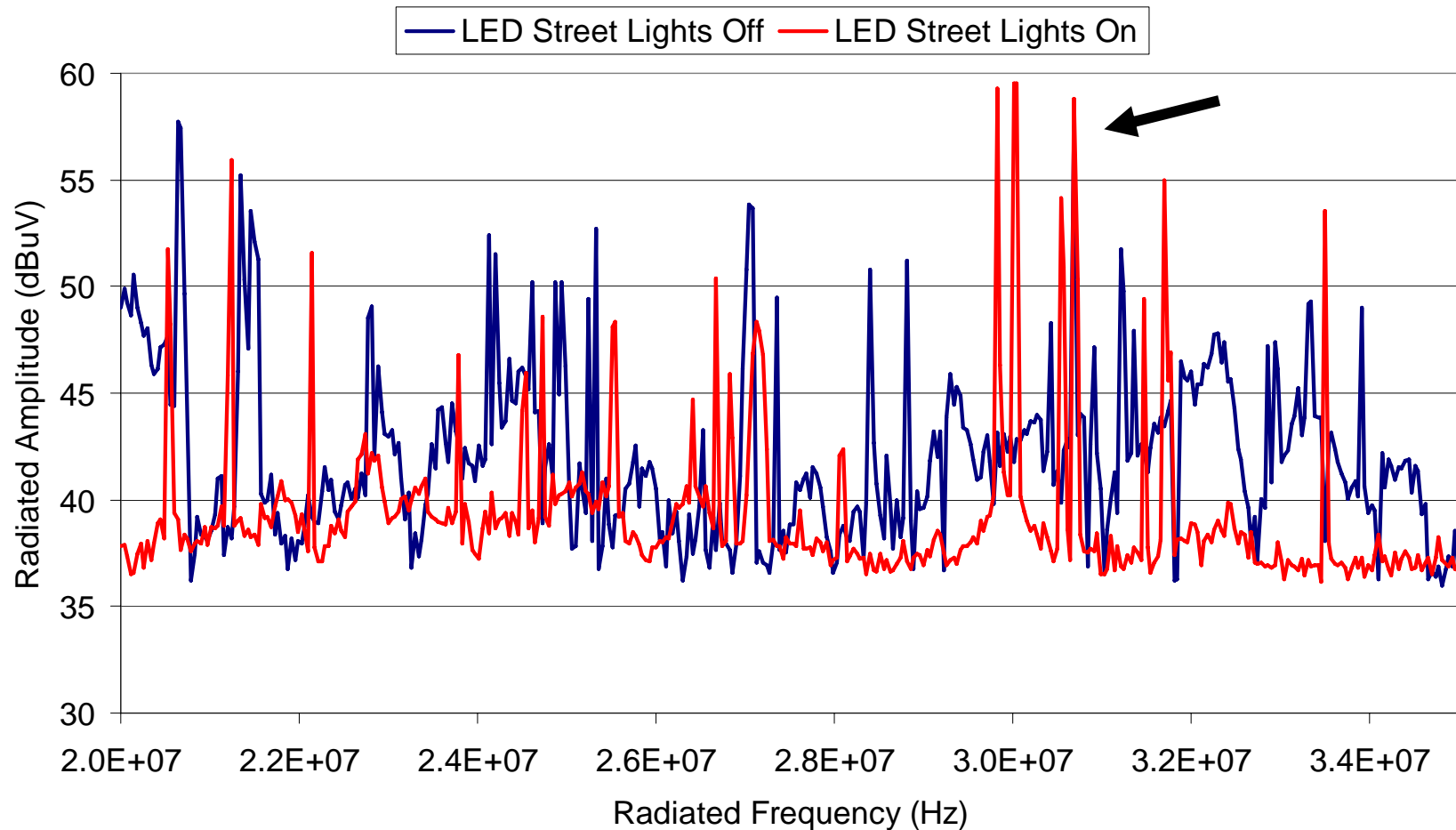
*Can I Still Use  
My HAM  
Radio?  
Maybe Not...*

Use of Ultrasonic  
Detector to Locate  
Noisy Distribution  
Hardware



# LED Fixture Found to be the Problem

Comparison of Radiated Emissions  
in Front of Customer's House: 20 MHz to 35 MHz



# How to Fix It...

## *Ferrite Cores...*

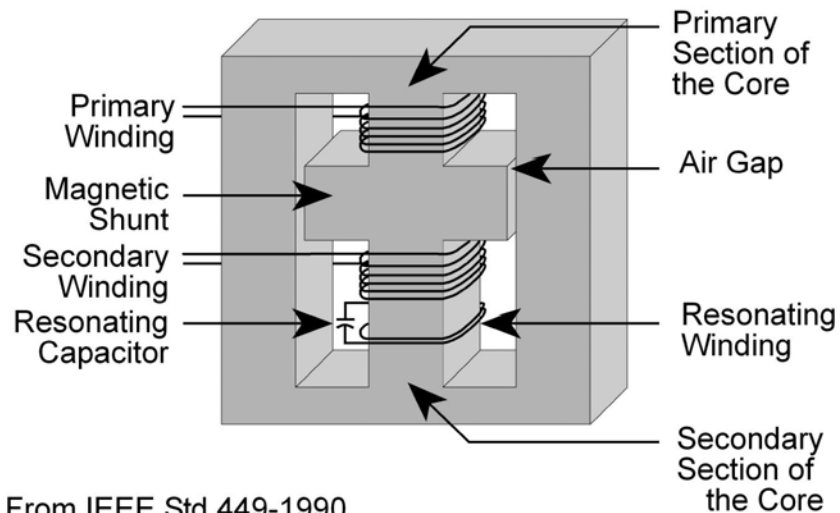


- **Electromagnetic Interference (EMI/RFI)**
  - Two types: conducted and radiated
  - Source: Power electronics such as an LED driver that use high-speed switches to increase efficiency.
    - The rapid on/off transition of the insulated gate bipolar transistors (IGBTs) generates a broad spectrum of electromagnetic energy
  - Several manufacturers have recognized their fixture as a **potential source for interference** and have taken preventative steps (ferrite cores).

EMI – Electromagnetic interference, RFI – Radio Frequency Interference

# Why Now?

- Street lights have been around a long time...
  - Magnetic ballast
  - Photocells
  - We've had problems in the past



## Magnetic Ballast

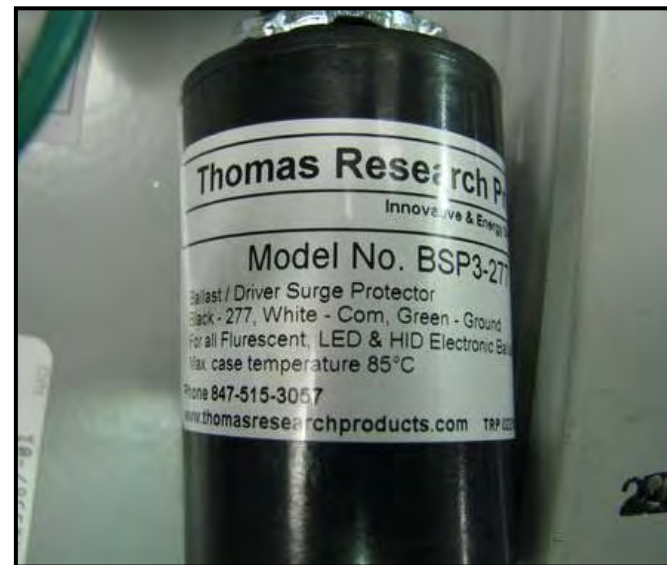
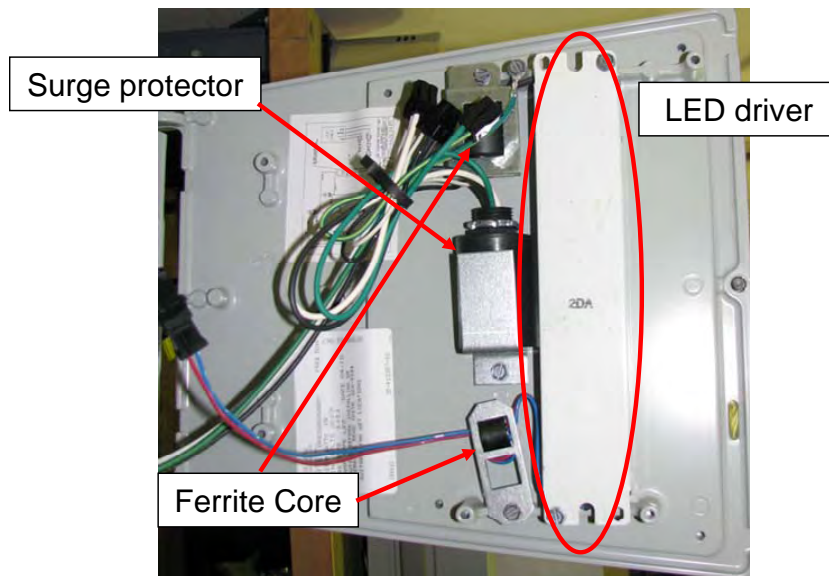


## Photocell

# Can't I Just Install a Surge Protection Device?

*Yes, but...*

- Which type?
- What should be the rating?
- How will it interact with other nearby surge protection devices?

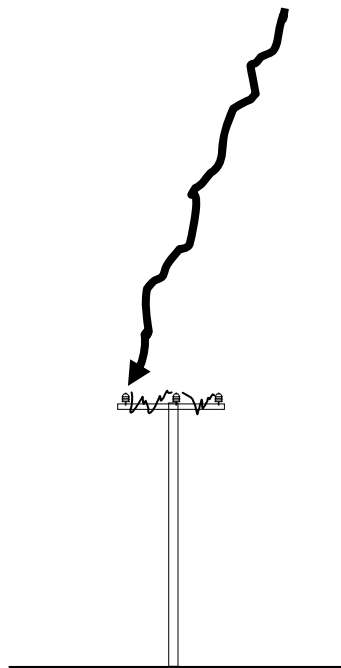


# Letting Out the Smoke

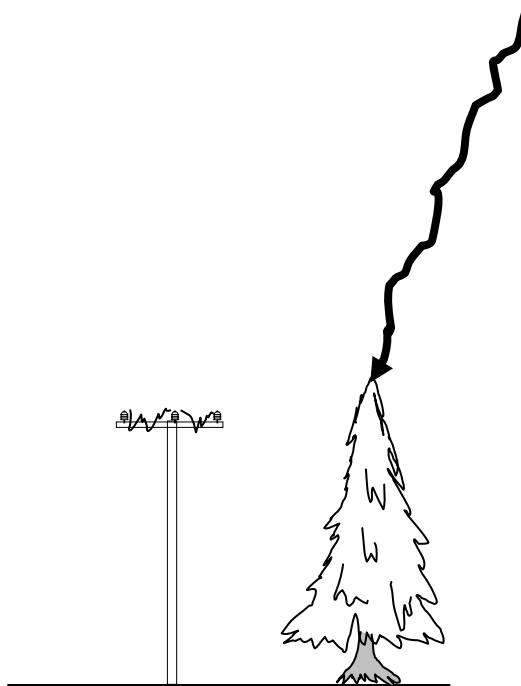




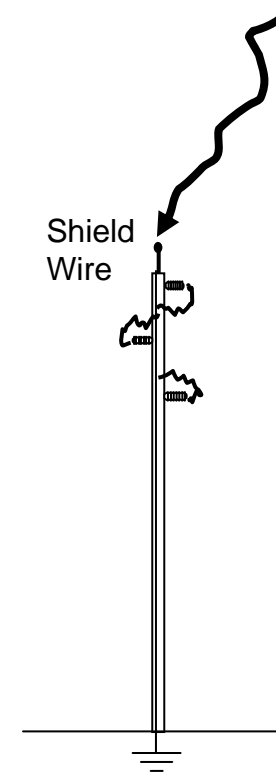
# Types of Line Flashovers



(a) Direct strike flashover



(b) Induced Flashover Due to Nearby Strike (electric and magnetic fields of nearby lightning create a voltage surge on line)



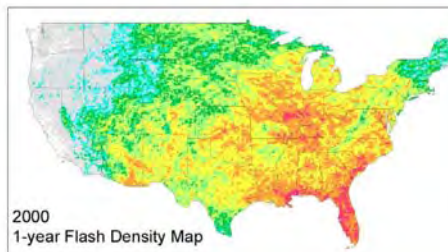
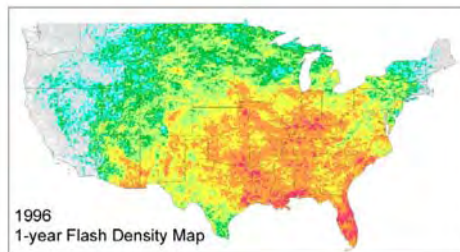
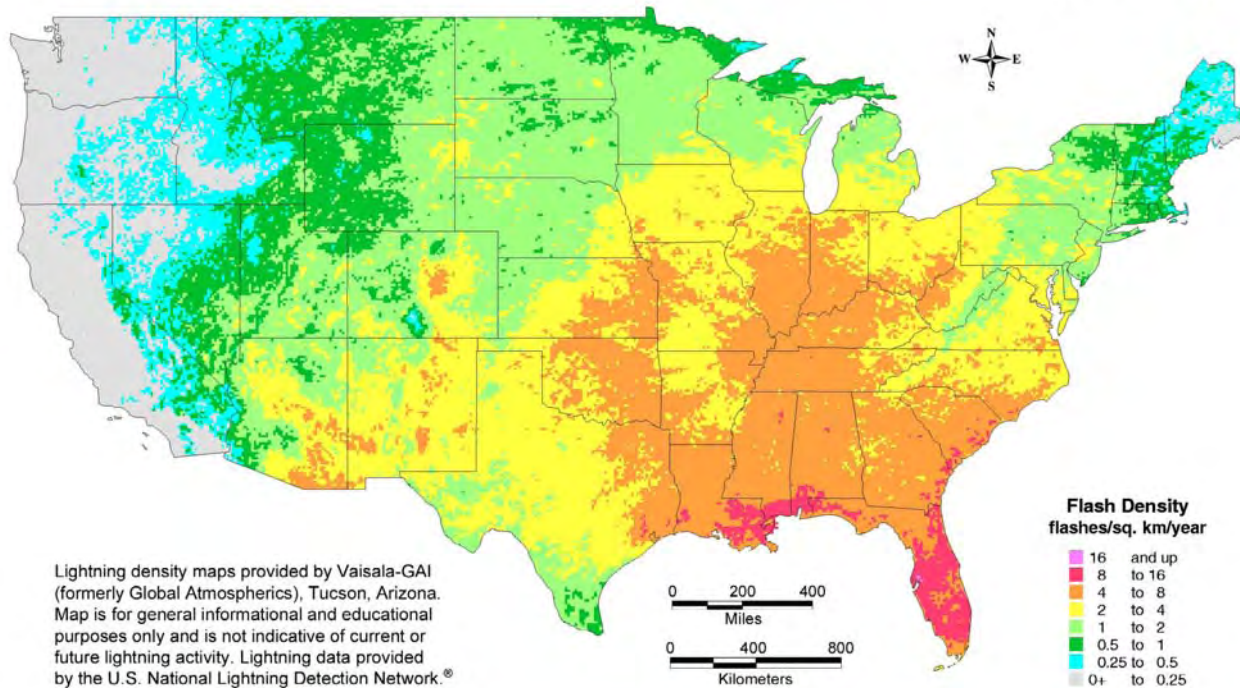
(c) Back-flashover: a strike to the grounded shield wire causes the local ground potential to rise resulting in flashover from pole grounding wire to phases

# Flash Density History

Important for Determining Risk Assessment and Protection Design and Calculations



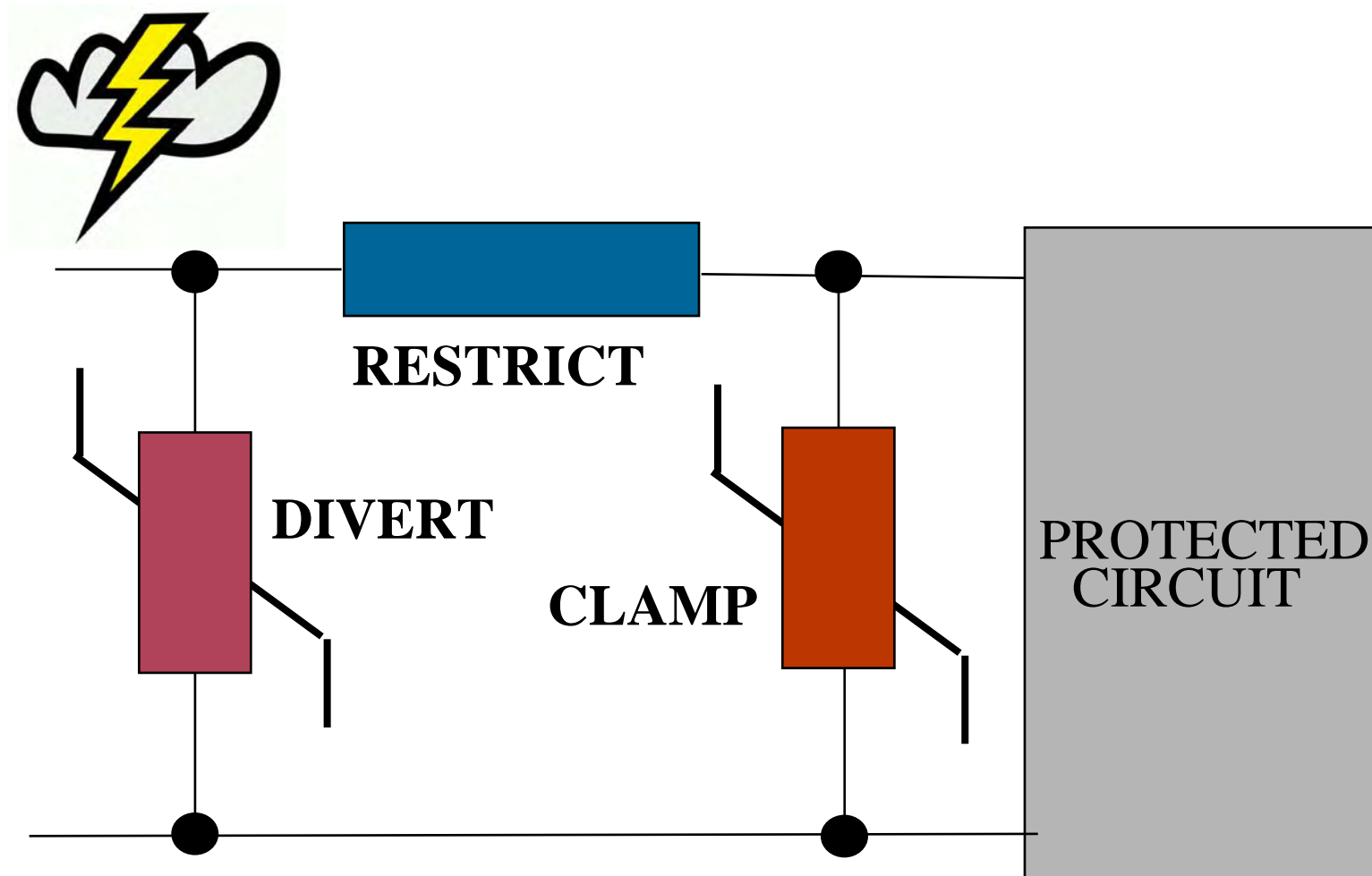
5-year Flash Density Map — U.S.  
(1996–2000)



The 5-year Flash Density Map shows the average amount of lightning recorded in 1996–2000. The average amount of lightning that occurs in any given area varies significantly from year to year, as shown in the annual maps for 1996 and 2000.

5-yr US density 1 annual\_96-00\_020402

# Methods of Protection



# How Do I Define the Environment?

1. Use existing standards to the extend possible
2. Laboratory testing
3. Site monitoring
4. Forensic analysis



# Standards for Immunity

Immunity	
Voltage sags/dips and momentary interruptions (cycles to seconds)	ITIC Curve; SEMI F47 Curve; IEC 61000-4-11, 61000-4-14, and 61000-4-34
Low RMS variations (seconds to minutes)	ITIC Curve, SEMI F47 Curve, ANSI/IEEE C84.1
Steady-state voltage variations	ANSI/IEEE C84.1
Voltage swells	ITIC Curve
Voltage unbalance	NEMA MG-1, ANSI/IEEE C84.1, IEC 61000-4-27
Voltage distortion	IEEE 519
Common mode noise	IEEE P-1100
Normal mode noise	IEEE P-1100
Switching transients	IEEE C62.45, IEC 61000-4-4 and 61000-4-5
RFI	IEC 61000-4-3, 61000-4-6
Frequency variation	IEC 61000-4-28

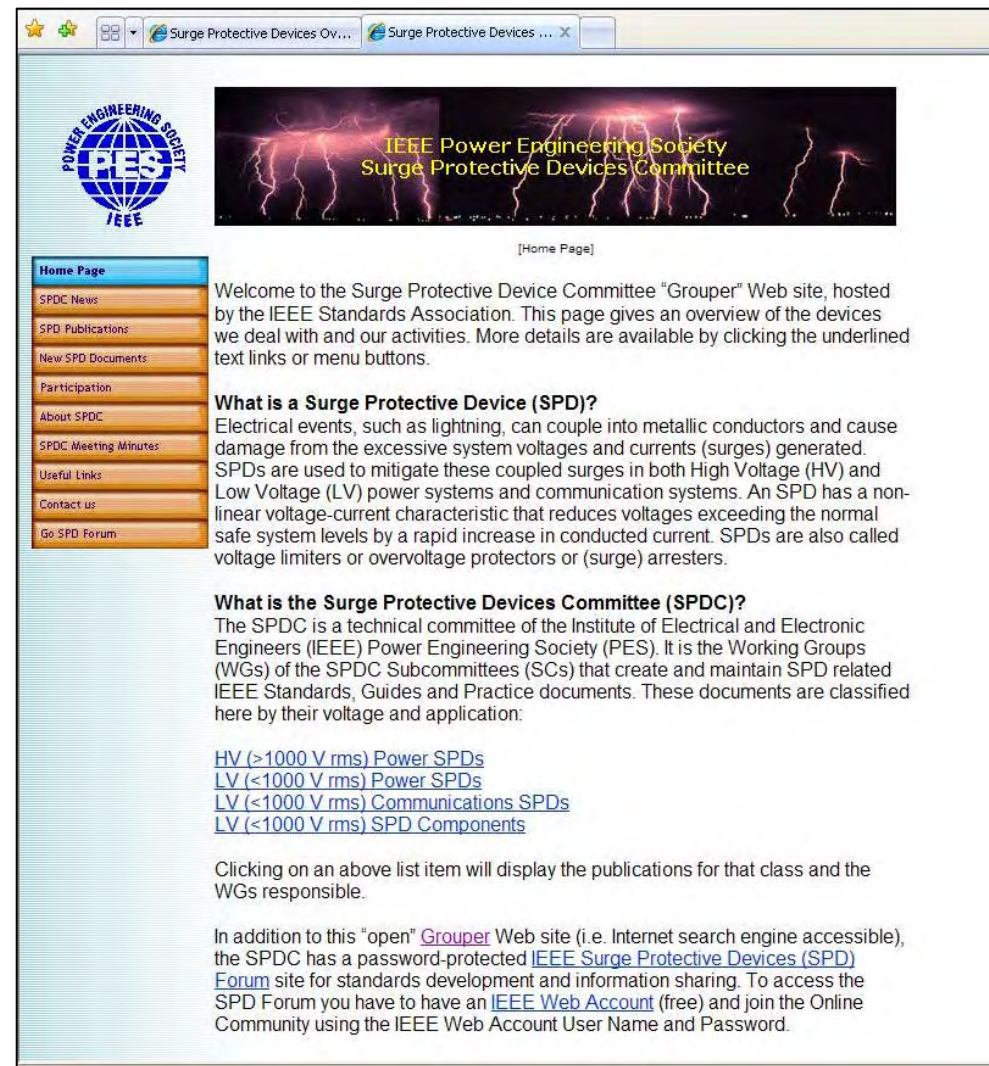
# Standards for Emissions, Survivability and Other

Emissions	
Current distortion	IEEE 519, IEC 61000-3-2 and 61000-3-4
Flicker	IEEE 1453; IEEE 141; IEC 61000-3-3, 61000-3-7, and 61000-3-11
Low-frequency magnetic fields	IEC 61000-2-7
Survivability	
Lightning transients	UL 1449, IEEE C62.45, IEC 61000-4-5
Overvoltage	ANSI/IEEE C84.1
All Types	
Event quantification	IEEE 1159, IEC 61000-4-30



# IEEE Surge Protective Devices Committee

- Meeting schedule and logistics can be found at:  
<http://grouper.ieee.org/groups/spd/>
- For more info contact Doug Dorr  
[ddorr@epri.com](mailto:ddorr@epri.com)  
407-787-0202



# What Can I Do?



## *The Road to Compatibility*

1. Define the environment
2. Establish emission criteria
3. Establish immunity criteria
4. Develop test and measurement procedures
5. Conduct product characterizations in cooperation with manufacturers
6. Design product improvements (manufacturers)

# Summary

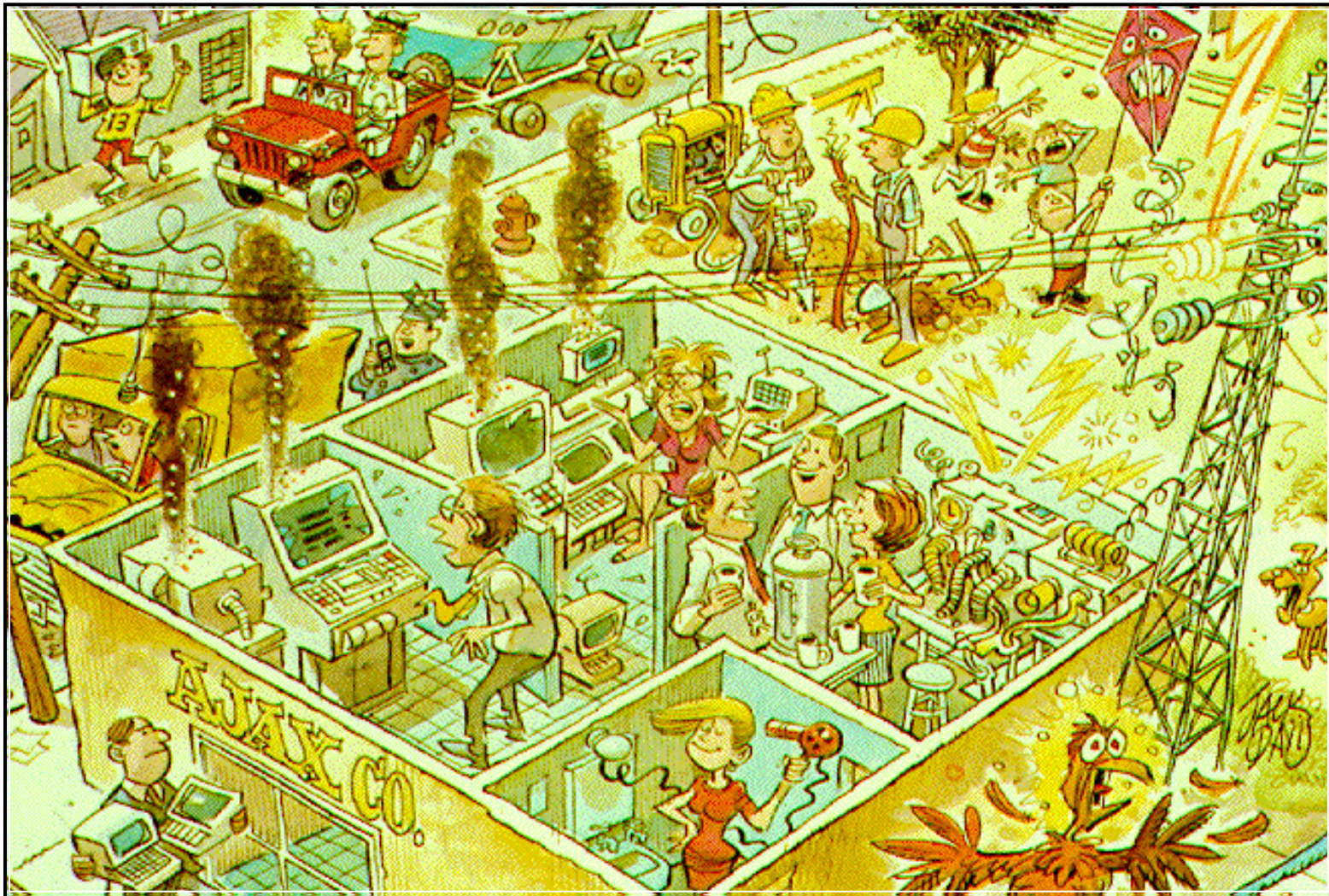
## *Remember*

- LEDs are part of the solution to a big problem. **It's worth it.**
- It's your money, your industry and your career. **Get it right.**
- The use of power electronics on the distribution line is new. **Don't forget about the driver.**
- Defining the electrical environment and then testing for compatibility will enable success. **More work is needed in this area – define then test.**

*“A magnetic ballast is inherently robust.  
Electronic ballasts and drivers are not.”*



# The Real World



Artist: Jack Davis

## Question...

- What sort of failures are we seeing now?





# **Together...Shaping the Future of Electricity**